Differential Raytracing for Exact Radiometric Calculations

M. Jahny, B. Michel
Hembach Photonik GmbH

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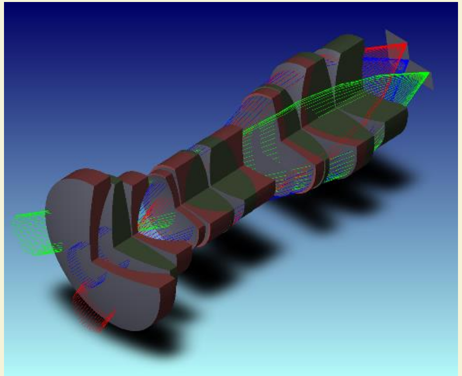
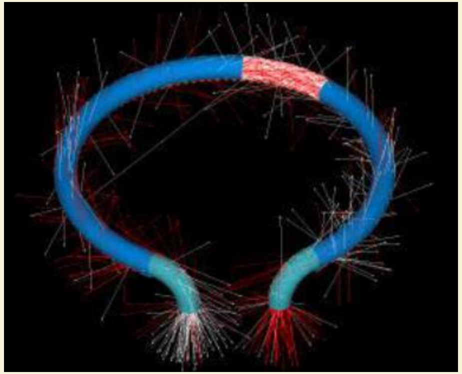
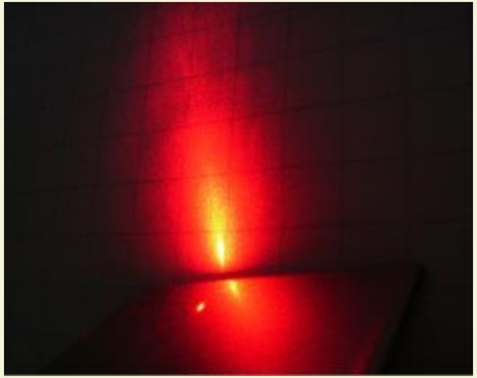
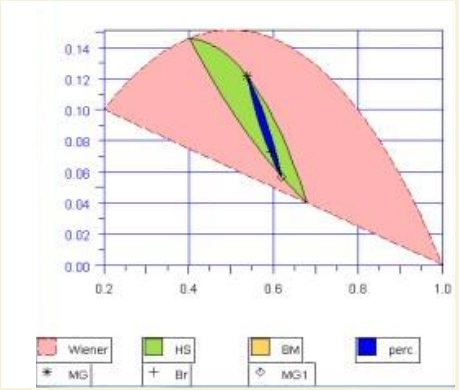
Key Areas

Imaging optics | Illumination optics | Straylight analysis | **Software development**









Small innovative company in Nürnberg Area, Germany

Currently 8 employees: physicists, mathematicians and engineers

Optical design and analysis for customers

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Overview

- Idea of differential raytracing
- Advantages of differential raytracing
- Example: Point light source
- Example: Collimated light source
- Applications and limitations

Gefördert durch:
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aufgrund eines Beschlusses des Deutschen Bundestages
ZIM Zentrales Innovationsprogramm Mittelstand

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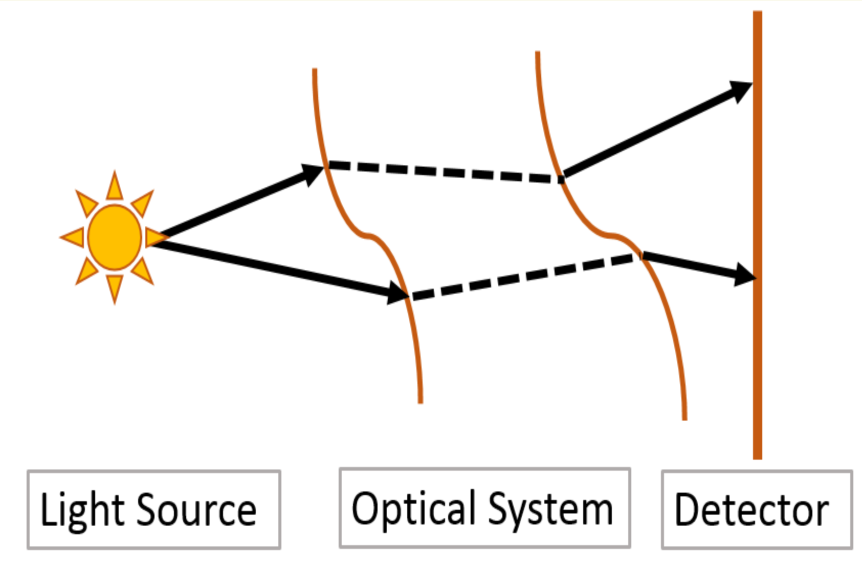
Motivation for Differential Raytracing

Non-Sequential Raytracing:

Compute radiometric quantities by tracing rays through optical systems

Conventional Raytracers

- Tracing of randomly generated rays (Monte-Carlo-method)
- Accuracy and computational time depend on number of rays

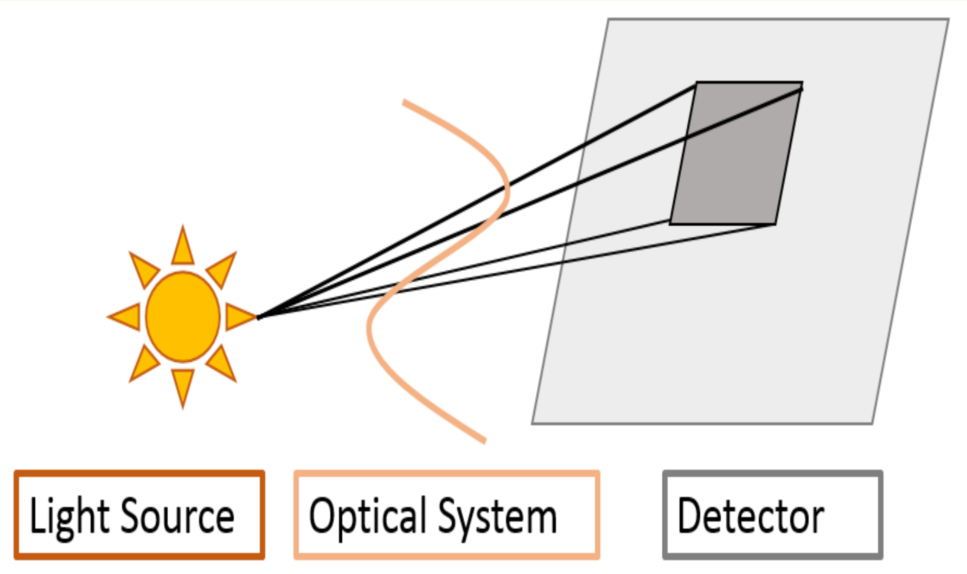


Idea of Differential Raytracing

- Trace ray bundles instead of single rays
- Ray bundles contain differential information

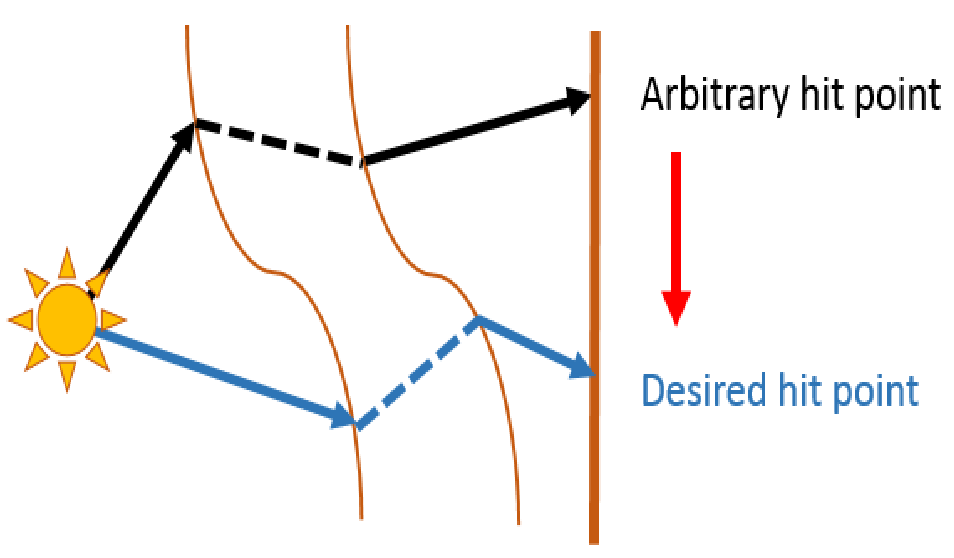
This enables us to:

- Move rays on detector
- Obtain exact irradiance value



Reaching All Detector Points

Vary ray bundle to possible hit points while keeping the start point



Consequence:
All possible detector points are reached

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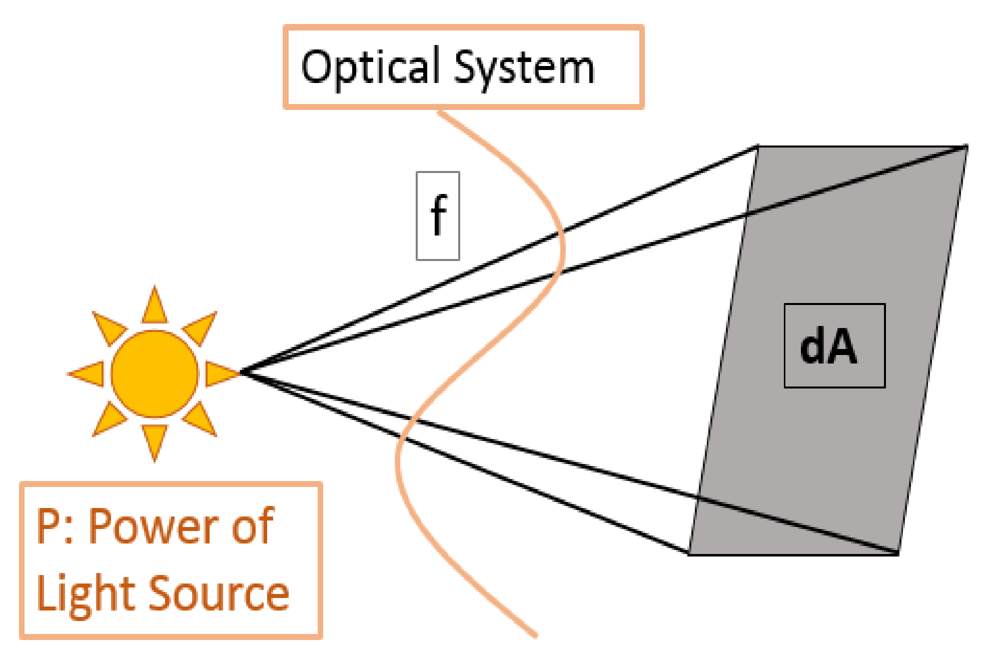
Getting Exact Irradiance Values

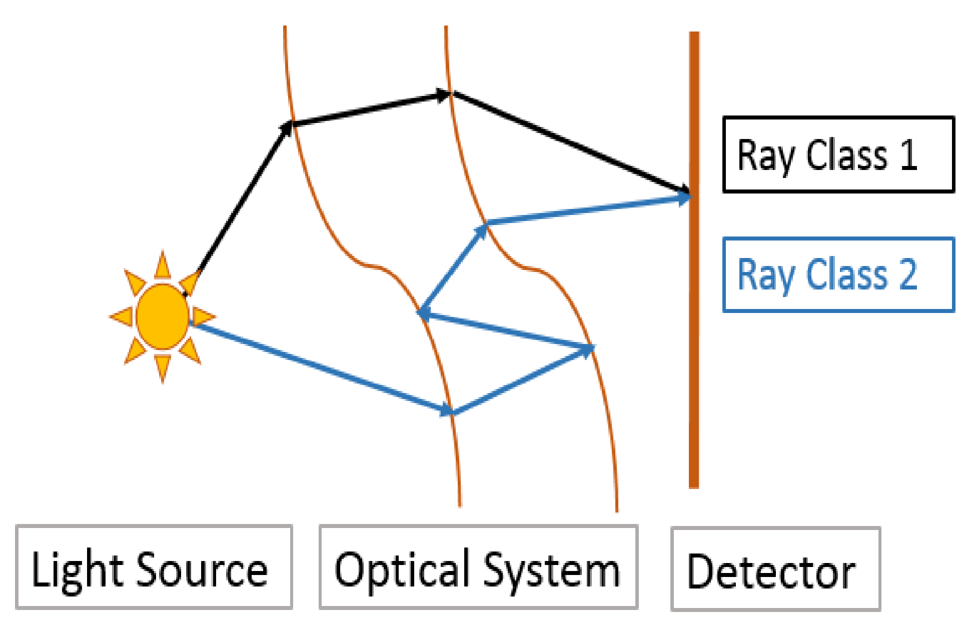
- **f:** Function describing optical system
- **Area dA:** Given by Jacobi-determinant of function f
- **Irradiance**: $E = \frac{dP}{dA}$



Consequence:
Information about derivatives of f leads to exact irradiance values

Equivalence Classes

- Specify equivalence classes for rays:
  - Number of hits
  - Hit objects
  - Start direction
  - Start point
  - … and other criteria
- Only one ray per equivalence class gives irradiance on reachable detector points



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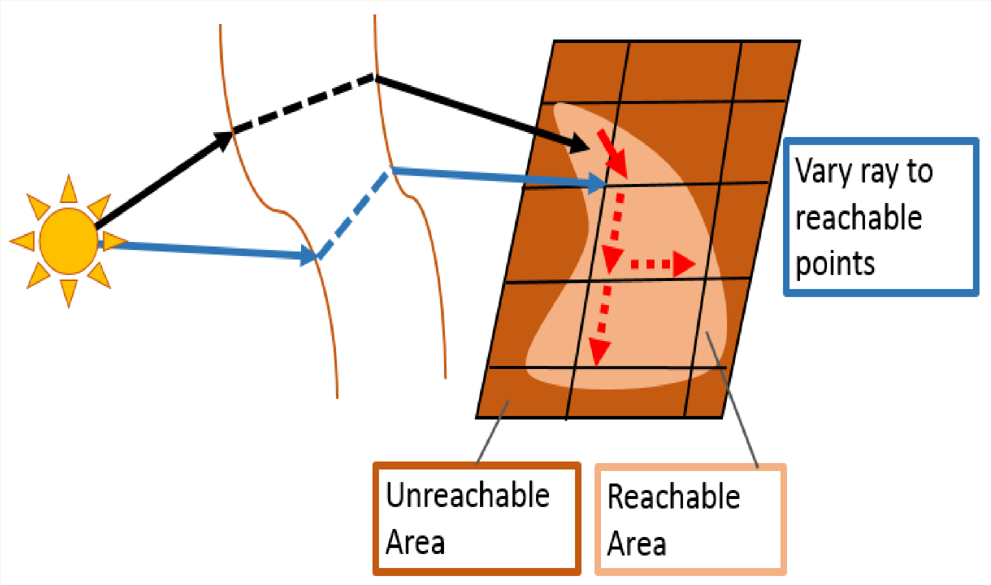
Advantages of Differential Raytracing

- Significant reduction of number of rays
- Consideration of all accessible detector points
- Exact irradiance value on all points



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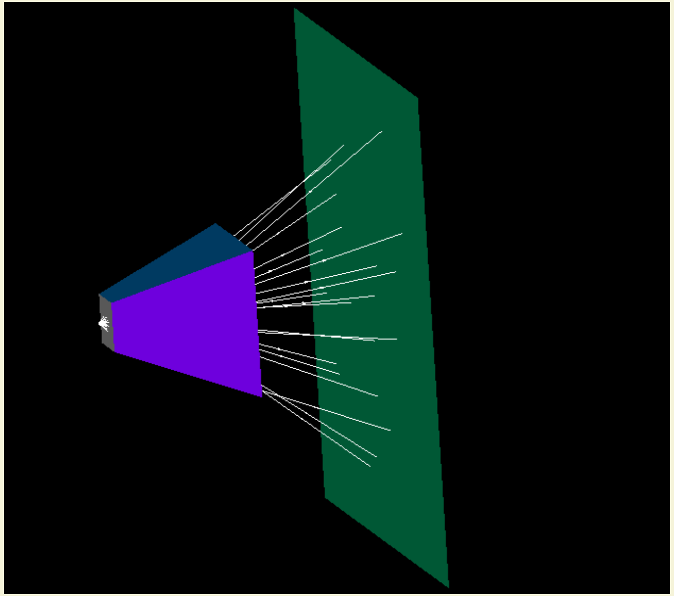
Example: Point Light Source



- Point light source
- Frustum (PMMA)
- Detector
- System with 9 relevant ray paths

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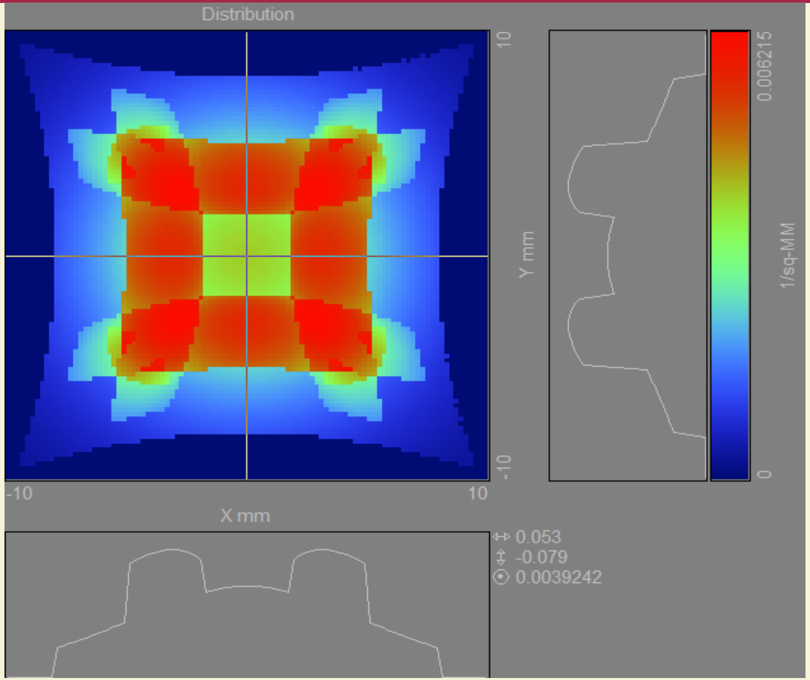
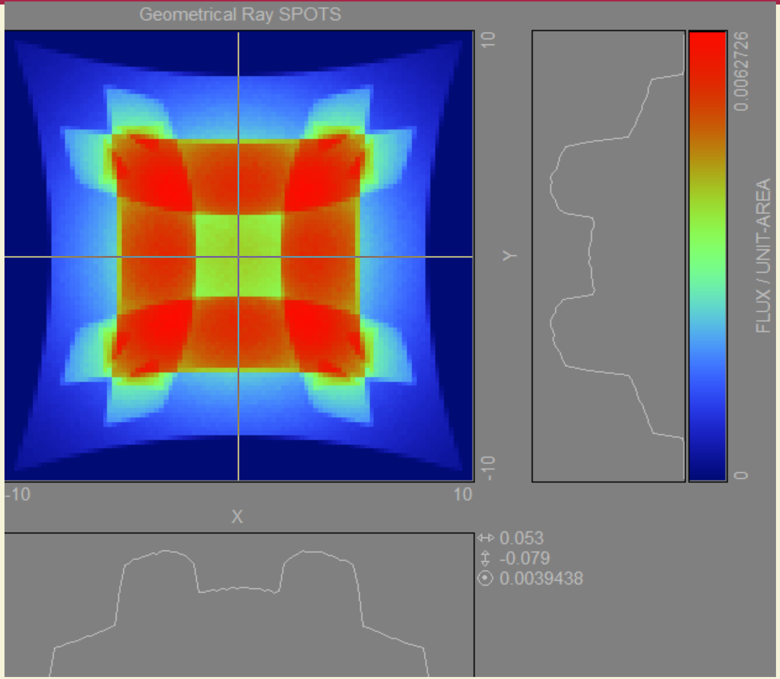
Irradiance on Detector



Differential raytracing, 10^3 rays



ASAP, 10^8 rays

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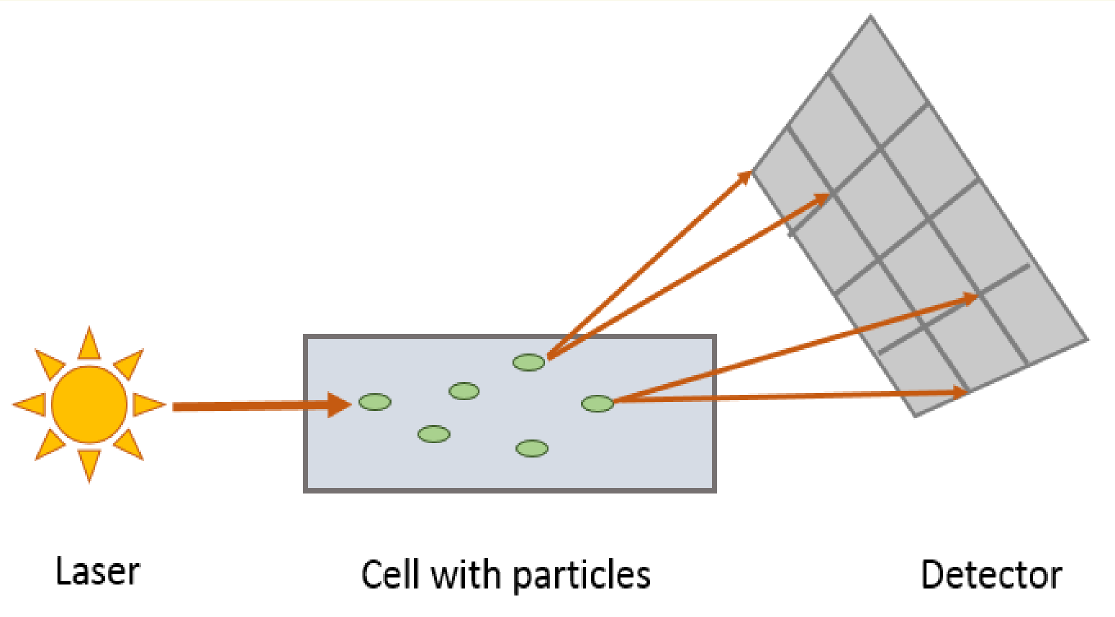
Example: Extended Light Source

Laser sends ray on particles in a measuring cell

Particles send light to detector as one extended light source

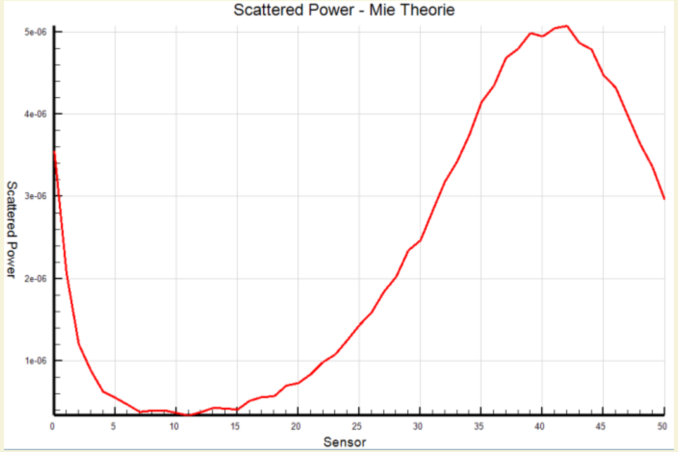
Vary rays on detector to compute scattered power on detector



Scattered Power

- **Scattered Power P_{det}:** Function of Scattering function and detector area
- **Detector area** given by Jacobi-determinant **J(r)**
- **Scattering function S(ϴ,φ)**
  from Mie- or Fraunhofer Theory
- **T(ϴ,φ):** Losses from transmission

$$P_{det} = \int_{z,A} T(\theta,\varphi)\mathbf{S}(\theta,\varphi)|\mathbf{J}(r)|^{-1}\ d(z,A)$$

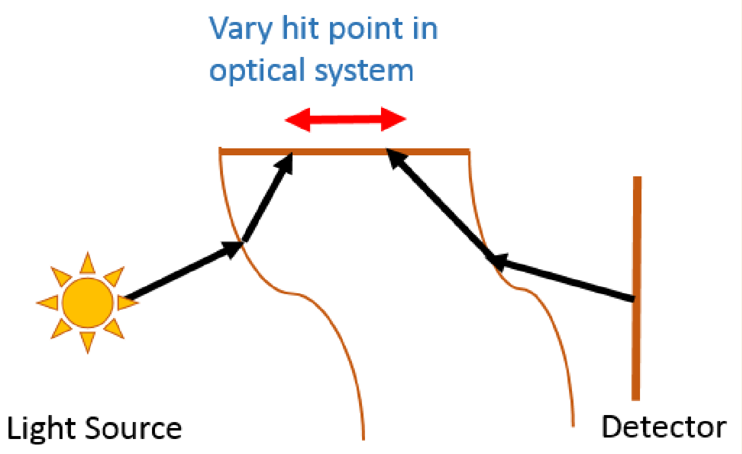


Scattering Power on 50 detectors with Mie-Theory

Applications and Limitations

Applications

- Stray light analysis



- … and many more

Open tasks / Limitations

- Unique identification of ray classes
- Classification of singularities
- Useful if number of ray paths not too big
- Design tool rather than analysis tool

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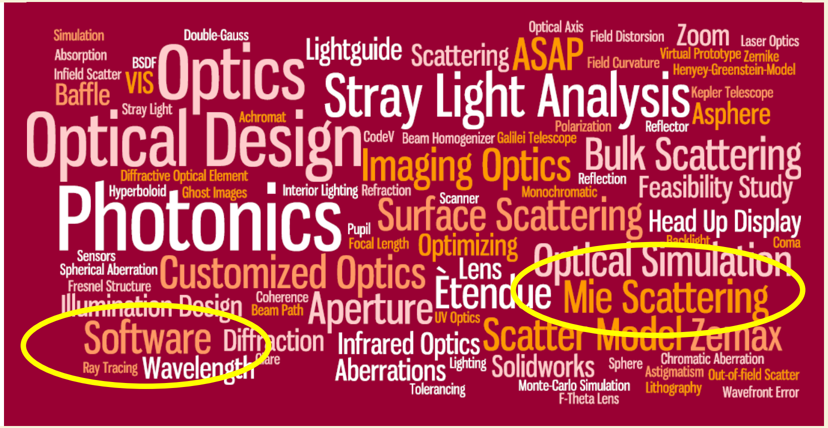
Responding author:

Melanie Jahny

E-mail mj@hembach-photonik.de

Tel. +49 (0) 9122 88 99 49-4

http://www.hembach-photonik.de



Thank you for your attention